ABSTRACT: Interface shear strength parameter evaluation for landfill liner systems have been a tedious testing process. Various testing methods and guidelines have been proposed by engineers and researchers over the years. However there is no specific testing methodology and apparatus adopted till today. The current testing procedures are based on ASTM testing guideline and basic fundamental engineering testing philosophies. Hence there is a need for much ideal testing equipment which can perform the entire test series required for landfill liner parameter evaluations. The equipment are required to perform 1) internal shear strength evaluation for geosynthetic clay liners, 2) interface shear strength between soil and soil, 3) geomembrane and soil, 4) geosynthetic / compacted clay liners and soil, 5) geomembrane and geotextile, 6) geotextile and soil, 7) geotextile and geosynthetic / compacted clay liners, 8) geomembrane and geosynthetic / compacted clay liners and finally conventional shear strength testing. The equipment is also required to perform the tests under fully saturated condition. Having such high requirement and testing complexity for landfill liner system, this paper addresses the various testing guides adopted to develop the ideal testing apparatus and methodology for landfill liner parameter evaluations. Large scale shear box apparatus is proposed to be used for the tests with adopted modification.

1 INTRODUCTION

The world consumption of natural resources have been increasing exponentially. In Japan the consumption of resource is at 1950 million tones annually. This consumption generates waste of 450 million tones, which consist of 400 million tons of industrial waste and 50 million tons of urban waste. Out of this 180 million tons are recycled and reused, 270 million tons are pre-treated waste for disposal. 90 million tons are used for landfill in Japan annually (Hiroshi Obana, 2000). United State however produce 300 million tons of solid waste per year. Up to 75% or 225 million tons of the solid waste continues to be landfilled in spite of vigorous effort aimed for waste reduction, recycling and reuse.

The estimated life spend of landfill site in Japan is about 6 to 7 years of operational. It is becoming impossible to build new sites in Japan cause of the syndrome of “Not In My Back Yard”. The cost of new site in Tokyo could cost up to 500 million US dollars. The running cost of existing landfill site in Tokyo is at 300 USD / m³ or 250 USD / tons

Industrial waste mainly consist of blast furnace slag, coal ashes, gypsum by product, dirt, sludge, nonferrous slag, coal tailing, steel manufactures slag, waste oil, waste tire and others. Where else incinerated urban waste ash contain harmful dioxins, heavy metals and large amount of chlorine (Hiroshi Obana, 2000).

Such a vast range of toxic material, constitute of Municipal Solid Waste need to be disposed systematically. Modern and well constructed landfill can be characterized as an engineered structure that consists primarily of a composite liner, leachate collection and removal system, gas collection and control system and final cover.

A landfill also behaves as in-situ bioreactor, where the contents undergo complex biochemical reactions. The adoption of suitable design and construction methods are essential not only to reduce design and construction cost, but also to minimize long term operation, maintenance and monitoring cost.
1.1 BASIC LANDFILL DESIGN

An engineered landfill site must be geologically, hydrologically and environmentally suitable. Landfills are not an open dump site. Nuisance conditions such as smoke, odor, unsightliness, insect, rodent, and seagull are not present in a properly designed, operated and maintained sanitary landfill. As such landfill site need to be carefully design to envelope the waste and prevent escape of leachate into the environment. Most important requirement of a landfill site is that it does not pollute or degrade the surrounding environment.

An engineered Municipal Solid Waste landfills consist of the following (Xuede Qian (2002):

i. Bottom and lateral side liners system
ii. Leachate collection and removal system
iii. Gas collection and control system
iv. Final cover system
v. Strom water management system
vi. Gas monitoring system

During construction or design of a landfill site, the engineers required to perform detail engineering evaluation on:

i. Landfill foot print layout
ii. Subsoil grading
iii. Cell layout and filling
iv. Temporary cover selection
v. Final cover grading
vi. Final cover selection

The above are directly relate to geotechnical engineering works which involves the use of ground improvement and slope stabilization technology. Although the issue of landfill and environmental stability is part of global environmental problem, it is essential to solve them one by one. Every geotechnical engineers are required to engage in the environmental engineering problems with the motto of “Think Globally, Act Locally” (Kamon 2001).

1.2 SCOPE OF ENVIRONMENTAL GEOTECHNICS

The definition of research fields of “Environmental Geotechnics” is not clear among the geotechnical engineers. The main research objects of environmental geotechnics are classified as “creation of better environment”, “prevention of environmental risks to human activities” and “prevention of danger on human life caused by natural hazards” (Kamon 1989). Tabulated below are the three major definitions or classification of environmental geotechnics.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Content</th>
<th>Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creation of better environment</td>
<td>Geotechnical activities aiming to improve the environment</td>
<td>Geotechnical creation of more comfortable and safe environment for human being</td>
</tr>
<tr>
<td>Prevention of environmental risk cause by human activities</td>
<td>Geotechnical activities causing environmental interference and/or avoiding risks in the geosphere</td>
<td>Ground settlement, soil erosion, ground vibration, obstacles of underground water, etc.</td>
</tr>
<tr>
<td>Waste containment and reuse of waste as geotechnical materials</td>
<td>Reclamation of MSW and industrial waste, Storage of radioactive waste, recycling, etc.</td>
<td></td>
</tr>
<tr>
<td>Remediation for the contaminated ground</td>
<td>Clean-up of polluted underground water and soil</td>
<td></td>
</tr>
<tr>
<td>Prevention of dangers on human life caused by natural hazards</td>
<td>Geotechnical activities for disaster prevention</td>
<td>Landslide, debris flow, liquefaction, volcanic eruption, etc.</td>
</tr>
</tbody>
</table>

The prevention of natural disaster should be considered as one of the most important research issues among the environmental geotechnical engineers. Movement of the earth materials during earthquakes, landslides, subsidence, volcanic eruption are to be considered as part of environmental geotechnics issues. The prevention of environmental risks cause by human activities is the most suitability associated with environmental geotechnical activities.

1.3 ENVIRONMENTAL ENGINEERING ASPECT OF LANDFILL

Environmental engineers have contributed to the development of engineered landfill site, safe to the environment. The major objective in constructing a safe disposal site is to:

i. Construction of liners, floors, walls and covers that adequately limit the spread of pollutants and the infiltration of surface water.
ii. Contain, collect and removal of leakage from landfill site
iii. Control, collection and removal or utilization of landfill gases
iv. Maintenance of landfill stability
v. Monitor and ensure that the necessary long term performance is achieved
The environmental standards were introduced to safeguard human health and to preserve the living environment. Effluent standards were introduced to control the water quality discharged from factories and other private establishments into public water and seepage of water into the ground.

The guidelines have contributed in developing suitable liners or hydraulic barriers for the landfill site. Early liners consisted primarily of a single liner composed of a clay layer or a synthetic polymeric membrane. During the past few decades the trend is to use composite liner systems comprising both clay and synthetic geomembranes together with interspersed drainage layers. The following is an approximate chronology showing the introduction date for each of these approaches.

- Pre – 1982 Single clay liner
- 1982 Single geomembrane liner
- 1983 Double geomembrane liner
- 1984 Single composite liner
- 1985 Double composite liner with primary and secondary leachate collection system

Double composite liners with both primary and secondary leachate collection system have been widely adopted in solid waste landfills in the United States. This type of liner system is mandated by Federal and State regulations for hazardous waste, in United States. Figure 1, shows a typical details of double composite liner system.

Progressively many other countries have imposed their own guidelines in bottom composite liners system. Figure 2 shows the various type of bottom lining system used in many countries.

Figure 1: Double Composite Liner System

1.4 GEOTECHNICAL ENGINEERING ASPECT OF LANDFILL

Geotechnical aspects of landfill involves the assessment of engineering properties of landfill components and design a stable landfill site against any mode of failure and avoid contamination to environment. Hence parallel to the development of clay liner system, intensive research have been carried out to study the slopes in landfill site for their stability during various kind of exposure to environment changes, internal and external hydraulic condition of landfill site and most importantly seismic stability of landfill.

Some recent landfill failures have indicated failures taking place along low friction angle zone between subsoil and geosynthetic or geosynthetic layers, clay liners, landfill cover slopes in static state or under seismic condition. This has lead to various researches to be carried on the shear strength and interface properties of subsoils, clay liners, geosynthetic and waste material. Most of the researches suggest the importance of geotechnical design in a landfill to prevent failures cause by low interface coefficient. Some studies have suggested to use sand clay or bentonite sand mixture with very low hydraulic conductively and improved shear strength properties (Xenxing 2001).

Figure 2: Bottom lining systems used in many countries (Kamon, 2001)
The weakest interface identified, is generally lower between a woven geotextile component of geosynthetic clay liner and the adjacent materials (David, 1998). The interface strength may be low in some parts because of bentonite or clay which tends to extrude through the opening in the relatively thin, woven geotextile and then into the interface as the clay liner hydrates. Design engineers are encouraged to consider clay liner with relatively thick, non woven geotextile components in critical situations where high interface shear strength is required. As the interface shear strength are dependent on many factors such as product type, hydration and shearing conditions and the specification of the equipment used to perform the tests (Eric J. Triplett, 2001).

Although technical issues associated with internal and interface direct shear testing of clay liner remain, it is gratifying to have documented field data that substantiate the current design process. Hence engineers are required to be careful in not designing slope that exceeds the safe slope angle for the clay liners or their respective interface within the system. For example, an infinite slope consisting of cohesionless interfaces with no seepage, the factor of safety (F) is (David E. Daniel, 1998):

\[ F = \frac{\tan \phi}{\tan \beta} \]

Where \( \phi \) = angle of internal friction; 
\( \beta \) = slope angle

Strain incompatibility with MSW could be another cause of stability failures. Example when failure occurs for the first, in the native soil, only a fraction of the MSW peak strength will be mobilized. As progressive failure occurs in the native soil, the peak strength of the MSW would be mobilized at a time when the shear strength of the native soil had declined to a value significantly below peak. This condition takes place cause by stain incompatibility between native soil and MSW. Similar condition is also applied for geosynthetic interface and foundation soils because of their strain incompatibility with the adjacent materials in stability analysis (Hisham 2000). Strain incompatibility could suggest the use of residual shear strength in stability analysis instate of peak shear strength. Higher displacement is required before residual shear strength is mobilized and it is lower then peak shear strength which can be mobilized with relatively minor displacement. In relation to this, the geosynthetic material should able to with stand such high displacement with continuous strength contribution for stability prior to tearing before native soil failures completely.

2 LANDFILL STABILITY

Stability of landfills has been a major concern of the present environmental geotechnical engineering community. Failures at landfill sites can be minor, however the cost of rectification is huge. As landfill sites generally used to contain solid waste of various kind, which some can contaminate and harm the environment. Hence landfill failures could lead to serious environment pollutions. However, stability is an issue that has be sometimes overlooked for the need of maximization of waste storage per unit area during continuous filling exceeding the initially design. In general majority of landfill sites are overfilled. Cincinnati landfill is an example of failure caused by overfilling and rapid expansion (Timoth 2000). Koerner and Soong (2000b) presented and analyzed ten large solid waste landfill failures, including Kettleman, Cincinnati and some of the world landfill failures. The ten solid waste failure can be generally characterized into (Wenxing Jian 2001):

i. Wide range failure in their geographic distribution  
ii. Extremely large in volume and lateral movement  
iii. Rapid and generally unexpected  
iv. Associated with excessive amounts of liquids (over, under or within the liner system); to the point where liquefaction take place.  
v. Involving extensive remediation which sometime include insurance and litigation cost

Table 2 : Summary of waste failures (Koerner and Soong, 2000)

<table>
<thead>
<tr>
<th>Case History</th>
<th>Location</th>
<th>Type of Failure</th>
<th>Quantity Involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Unlined Sites)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U-1 - 1984</td>
<td>North America</td>
<td>Single</td>
<td>110,000 m³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rotational</td>
<td></td>
</tr>
<tr>
<td>U-2 - 1989</td>
<td>North America</td>
<td>Multiple</td>
<td>500,000 m³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rotational</td>
<td></td>
</tr>
<tr>
<td>U-3 - 1993</td>
<td>Europe</td>
<td>Translational</td>
<td>470,000 m³</td>
</tr>
<tr>
<td>U-4 - 1996</td>
<td>North America</td>
<td>Translational</td>
<td>1,100,000 m³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Single</td>
<td>100,000 m³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rotational</td>
<td></td>
</tr>
<tr>
<td>(Lined Sites)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L-1 - 1988</td>
<td>North America</td>
<td>Translational</td>
<td>490,000 m³</td>
</tr>
<tr>
<td>L-2 - 1994</td>
<td>Europe</td>
<td>Translational</td>
<td>60,000 m³</td>
</tr>
<tr>
<td>L-3 - 1997</td>
<td>North America</td>
<td>Translational</td>
<td>100,000 m³</td>
</tr>
<tr>
<td>L-4 - 1997</td>
<td>Africa</td>
<td>Translational</td>
<td>300,000 m³</td>
</tr>
<tr>
<td>L-5 - 1997</td>
<td>North America</td>
<td>Translational</td>
<td>1,200,000 m³</td>
</tr>
</tbody>
</table>
The failure commonly occurs along liner slope, through landfill foundations, surface side slope and within the waste mass itself. In addition to such failures, failures have also occurred during cell excavation, liner system construction, waste filling and after landfill closure. All of it is a classical geotechnical mode of failure depending upon site specific conditions, the placement and geometry of the waste mass (Xuede Qian, 2003). Potential failure mode include the following:

i. Sliding failure along the leachate collection system
ii. Rotational failure along sidewall slope and base
iii. Rotational failure through waste, liner and foundation subsoil
iv. Rotational failure within the waste mass
v. Translational failure by movement along the underlying liner system

The failures through liner system beneath the waste mass are common, caused by multiple layer component consist of clay, soils and geosynthetic materials. Double-lined system can consist of as many as 6 to 10 individual components. As such the interfaces resistance of the individual components against shear stress could be low and cause potential failure plane. Figure 3 and 4 shows the type of potential failure along the liner system.

The liners and closure cover system of a modern municipal solid waste (MSW) landfill are constructed with layers of material having dissimilar properties, such as compacted clay or geosynthetic clay liner, geomembrane (liquid barrier), geonet (drainage layer), geotextile (filter) and geogrid (reinforcement). Typical detail of such system is shown in Figure 5.

While compacted clay or geosynthetic clay and geomembranes function effectively as flow barriers to leachate and infiltration, their interface peak and residual friction angles are lower than those of the soil alone. Such lower friction angle between a geomembrane and other geosynthetics could trigger much rapid failure during seismic loading conditions.

The soil-geomembrane interface acts as a possible plane of potential instability of the system under both static and seismic loading (Hoe I. Ling, 1997). Hence environmental geotechnical engineers are very concern about the potential instability caused by the waste containment liner system.

Figure 3 : Failure Completely Along (or Within) Liner System (Xuede Qian, 2003)
Figure 4 : Failure Along (or Within) Liner System and Solid Waste (Xuede Qian, 2003)
Figure 5 : Cross section of typical bottom liner systems (Kamon, 2001)

Attention to slope stability of municipal solid waste during static and seismic loading has increased following report of Kettleman Hills waste landfill failure. The cause of failure was due to low friction angle between the soil and geosynthetic or geosynthetic layers in the liner system.
This failure however was not attributed to seismic loading. Seismic performance of landfills has been reported for the 1989 Loma Prieta Earthquake and the 1994 Northridge Earthquake. Seismic design of landfill systems should include response analysis, liquefaction analysis, deformation analysis and slope stability analysis. Shear failure involving liner system can occur at three possible locations:

i. The external interface between top of liner system and the overlying material
ii. Internally within the liner system
iii. Interface between clay liner and geosynthetic layer
iv. The external interface between the bottom of the liner system and the underlying subsoil material

Current engineering design practice is to establish appropriate internal and interface shear strength parameters for design using direct shear test on test specimens and employing traditional limit equilibrium techniques for analyzing the landfill slope stability (David E. Daniel, 1998). As such simplified Janbu analysis procedure is recommended as it often gives factor of safety that is significantly less than those calculated by Spencer’s procedure (Robert B. Gilbert, 1998).

3 PROPOSED RESEARCH OUTLOOK

The above discussion calls for detail and compressive study of landfill stability on the following:

1. Study landfill liner component, their internal shear strength and external interface properties
2. Liner geosynthetic material and physical properties.
3. The effect of normal stress on liner system and its influence on interface properties
4. Study the compacted clay liner (CCL) internal shear strength and external interface properties with geomembrane and geosynthetic clay liners.
5. Study the interface property of compacted clay liners (CCL) and geosynthetic clay liner (GCL) with native soils.
6. Study the interface property between CCL, GCL, non woven geotextile and geomembrane.
7. Study the suitable configuration of composite liner system which could improve the liner stability without neglecting the hydraulic conductivity requirement.
8. Conduct detail stability analysis study of various configurations of landfill liner using the data from laboratory study, using limit equilibrium method.
9. Prepare a manual for landfill stability design and installation guide for landfill liner and cover soil to improve overall stability of landfill site by providing sufficient strain compatibility within the component members.

3.1 PROPOSED LANDFILL LINER CONFIGURATION FOR TESTING

The list of testing conducted will be dependent on the configuration and the material used for landfill liner system, adopted for research. Following figure 6 shows the sample configuration proposed for research.

![Figure 6: Proposed Detail of Landfill Liner Configuration for Research](image)

Proposed material details are as follows:

i. Toyoura Sand is proposed to be used as sand
ii. One type of Non Woven Geotextile is proposed
iii. Geomembrane  
   a. HDPE Geomembrane  
      • Type 1 – Smooth non textured  
      • Type 2 – Textured membrane  
   b. PVC Geomembrane - Smooth non textured  

iv. Clay Liners  
   a. Fukakusa Clay and Bentonite Mix (10 %)  
   b. Sand and Bentonite Mix (10 %)  
   c. Geosynthetic Clay Liner (GCL)  
      • GCL Type 1 – Adhesive-bond clay to upper and lower non woven geotextile  
      • GCL Type 2 – Adhesive-bond clay to geomembrane  

v. Native Soil type - Decomposed granite soil  

Textured and non textured geomembrane is proposed for the study to validate the interface properties due to plowing. Where the measured friction coefficient for smooth particles is relatively low and plowing is not an important contributor. Whereas rougher and more angular particles have relatively larger friction coefficients and plowing is important even at low normal loads. (Joseph E. Dove, 1999).  

Modified large scale shear box is proposed to be used to study the interface properties. The shearing machine is required to have maximum normal load of 350 kPa and shearing speed of 1 mm/min with maximum shearing displacement of 50mm to 100mm. Each interface configuration test are proposed at be tested for normal loads of 100, 200 and 350 kPa to obtain the interface properties.  

4 TESTING APPARATUS DESIGN GUIDE  
The modified large scale shear box for the interface shear strength evaluation for landfill liner system was developed based on the guideline of  


As per the above guideline and testing requirement the apparatus design is subdivided into three categories, namely  

i. Soil and soil internal and interface testing apparatus to perform test on  
   • Interface shear strength between native soil and compacted clay liner  
   • Internal shear strength of native soil and compacted clay liner  

ii. Geosynthetic and geosynthetic internal and interface testing apparatus to perform test on  
   • Internal shear strength evaluation of geosynthetic clay liners  
   • Geomembrane and geotextile  
   • Geotextile and geosynthetic clay liners  
   • Geomembrane and geosynthetic clay liners  

iii. Geosynthetic and soil interface testing apparatus to perform test on  
   • Geomembrane and native soil / compacted clay liner  
   • Geosynthetic clay liners and native soil  
   • Geotextile and native soil / compacted clay liner  

All the above specified experiment are required to be conducted under both saturated and at optimum moisture content. Hence the equipment should meet the necessary guideline on sample saturation procedure and verification process. Following are the design guide adopted to modify the large scale shear box  

i. Shear Box Design Guide  
   a. The shear box size shall have a minimum size of 300mm x 300mm or 15 times the $d_{55}$ of the coarse soil sample used, or 5 times the maximum opening size (in plan) of the geosynthetic to be tested. The adopted shear box size is 300mm x 500mm.  
   b. The shear box height shall have a minimum height of 50mm or 6 times the maximum particle size of the coarse soil used. The adopted box height ranges between 75mm to 150mm.
c. Test failure is defined as shear stress at 15 % to 20 % of relative lateral displacement. The shear box is designed to have maximum displacement of 100mm which is 20 % of 500mm of shear box length.

d. The top and bottom plate should be porous to allow dispersion of pore water pressure during shearing. Hence porous stones are placed at top and bottom of box to disperse the built up pore water pressure.

e. The box is required to be made of stainless steel with sufficient thickness to avoid box deformation during loading and shearing. Hence box thickness of 12mm is proposed.

f. For soil and soil interface shear strength, the top and bottom box should be able to slide up and down in order to predetermine the shear plane parallel to the faces of the specimen.

g. The top and bottom box opening shall be \( \frac{1}{2} \) of \( d_{3S} \) or 1mm.

h. Pore water pressure needles are proposed to be used at 10 locations within the shear box to measure the sample pore water pressure build up during shearing. The pore water pressure needles are placed just above the shearing plane.

i. The shearing process should be fully drained condition at top, bottom and within the shearing plane.

ii. Geosynthetic (Geosynthetic Clay Liner or Geomembrane) Clamping Guide

a. In general flat jaw like clamping device is sufficient. However for geosynthetic clay liner, internal shear resistance an aggressive gripping surface is required. Rough textured surface can be used on the top and bottom of geosynthetic clay liners. The plate could be similar to the metal connector plates used for wood truss construction, with spikes or roughen surface.

b. The clamping surface should permit flow of water through the sample.

c. The gripping surface should prevent the outside surface of geosynthetic being sheared from slipping during shearing process.

d. The gripping surface should completely transfer the shear stress through the outside surface into the geosynthetic.

e. The gripping should not damage the geosynthetic and should not influence the shear strength behavior of the geosynthetic.

f. The failure surface should be entirely within the geosynthetic member.

g. Geosynthetic gluing is not allowed as it will influence the physical properties of the geosynthetic.


a. Determine the received geosynthetic clay liner water content as whole

b. Add sufficient water in shallow pan and allow the geosynthetic clay liner for 2 days hydration with 1 kPa normal aerial load.

c. Apply the required normal stress for 2 days under consolidation process, record the vertical displacement and pore water pressure to determine the completion of consolidation process

d. Determine water content of geosynthetic clay liner as whole before and after shearing process.

e. Insert pore water pressure needles within the geosynthetic clay liner to measure pore water pressure during saturation, consolidation and during shearing.

iv. Shearing Process Guide

a. The shearing machine is required to have a range of displacement rate of 0.025mm/min to 6.35mm/min however the proposed testing procedure will adopt a displacement rate of 1mm/min due to machine constrains.

b. Apply the normal seating load and monitor the vertical displacement and pore water pressure until equilibrium during consolidation process prior to shearing.

c. The normal loading plate shall have 0.2 to 0.5mm lesser dimension than the inner box dimension.

d. The load cell or proving ring shall have an accuracy of 2.5N the record or monitor the shearing forces.

e. Vertical displacement measuring device shall have an accuracy of 0.0025mm with maximum displacement of 25 ~ 50mm
f. Horizontal displacement measuring device shall have an accuracy of 0.025mm with maximum displacement of 120 ~ 150mm.
g. LVDT – Linear Variable Differential Transformer is proposed to be use to measure displacements.

The above listed is the summary of interface and internal shear strength requirement base on the guideline in BS1377, Part 7, 1990, ASTM D3080-98, ASTM D5321-02 and ASTM D6343-98. With such stringent guide and testing complexity, much attention was paid to modify the conventional shear box to meet the standard guideline. Figure 7 below shows the modified design shear box for

![Modified Shear Box Diagram](image)

Figure 7 : Shows the apparatus proposed to be used for geosynthetic and soil interface testing.

5 CONCLUSION

Based on the testing requirement as per the guide line of ASTM the designed apparatus are shown in figure 7 is a representative modified shear box to conduct the interface test on:

i. soil and soil interface testing
ii. geosynthetic and geosynthetic internal and interface testing
iii. geosynthetic and soil interface testing

The design equipment is expected to perform as required and obtained much reliable data. However the data from the tests shall be compared with the various data source to validate the data reliability. Subsequently the modified direct shear box test method will be improved in order to be a test guide for practicing engineers. The method of data interpretation will also be investigated as the proposed testing covers both saturated and at optimum moisture condition.

Finally the proposed modified direct shear box is expected to be adopted for interface testing for landfill liners, as compared to various other method of interface testing such as the pullout method.

REFERENCES


